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Applicability of weathering steel in the atmospheric conditions of Bangladesh

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ABSTRACT: This study examined the feasibility of using weathering steel in the atmospheric conditions of Bangladesh. Exposure tests were conducted at six different locations in Bangladesh for five years, and, to understand their influence on the corrosion of weathering steels, environmental parameters (including the amount of airborne salt, temperature and relative humidity) were also measured at four test sites. The corrosion losses of different grades of weathering steels and conventional steel were measured during the study period. The maximum amount of airborne salt appeared in May. No dependence appeared between the distance from a coastline and the amount of airborne salt. In Bangladesh, airborne salt may come from secondary sources, like soil dust. The corrosion loss of weathering steel over time was less than that of the conventional steel. Corrosion losses in 1 year were under 0.03mm at each exposure test site. The predicted corrosion losses using 1,3, and 5 years of data were under 0.5 mm over100 years at each exposure test site. According to Japanese corrosion loss criteria, weathering steel can be used in Bangladesh.

1 INTRODUCTION

The flood plains of the Ganges, Brahmaputra, and Meghna rivers cover approximately 40% of the total geopolitical area of Bangladesh. The Ganges comprises the largest area by far of this Indo-Bangla delta. The Ganges, the Brahmaputra-Jamuna, the Surma-Meghna, and the Padma—and their numerous tributaries and distributaries—are arteries of the country's drainage system. In this geological formation, constructing and maintaining uninterrupted road–rail, telecommunication, and power transmission networks across the country poses the biggest challenge for civil engineers (Amin and Okui 2015). In Bangladesh's rapidly growing economy, some steel bridges have served people for about the last 100 years. To maintain steel structures, however, maintenance engineers must combat corrosion by painting and repainting all year, which increases maintenance costs.

The steel structures' direct exposure to natural environmental moisture and airborne contaminants causes steel structures to corrode and consequently lose thickness at a rate that depends primarily on the exposure conditions and on the steel's characteristics. Under suitable atmospheric conditions, weathering steels can be used without painting because a compact, adhesive, and protective rust layer forms on the steel surface that reduces the corrosion rate to a technically permissible limit. To reduce structures' (such as bridges) life-cycle maintenance costs, weathering steels are used in many countries(Horii et al. 2015). In the rapid growing infrastructure of Bangladesh, where the climate is hot and humid with presumably low airborne salinity, studying weathering steel's applicability can help reduce the life-cycle cost of steel structures. The corrosion behavior of weathering steels is influenced by environmental factors, such as temperature, relative humidity, airborne salt, and so on. Many studies on the relationship between weathering steel's corrosion behavior and environmental factors have come from Japan (Kage et al. 2006, Horii et al. 2015, Miura et al. 2016) and from elsewhere(Hopwood et al. 2016). In this study, we measured environmental factors and the thickness loss of weathering steels to investigate environmental factors' influence on the corrosion behavior of weathering steels in Bangladesh.

2 EXPERIMENTAL PROCEDURE

In this study, various types of weathering steels and plain carbon steel were exposed in the environmental conditions of Bangladesh at six locations between 2014 and 2020.The test sites’ details appear in Figure 1 and in Table 1.The chemical compositions of the weathering steels and of the plain carbon steel appear in Table 2.

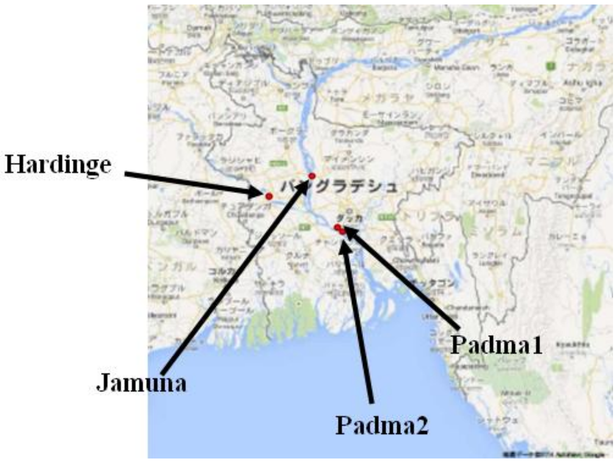

Figure 1. Test site locations.

Table 1. Details of exposure test sites.

Site Name	Location	District	Geo-coordinate
Padma 1	Dohar	Dhaka	23°31'39.99"N, 90°10'31.60"E
Padma 2	Maoa Old Ferry Ghat	Munshigonj	23°28'31.59"N, 90°15'13.32"E
Hardinge 1	Hardinge Bridge pier top between Span 5 and Span 6	Kushtia	24° 4'1.64"N, 89° 1'38.41"E
Hardinge 2	Hardinge Bridge pier top between Span 10 and Span 11	Pabna	24° 4'6.79"N, 89° 1'56.79"E
Jamuna 1	Jamuna Bridge Pier 2	Sirajgonj	24°23'55.54"N, 89°45'17.92"E
Jamuna 2	Jamuna Bridge Pier 47	Tangail	24°23'50.08"N, 89°47'56.66"E

Table 2. Chemical composition of specimens (mass%).

C	Si	Mn	P	S	Cu	Ni	Cr
0.08	0.19	0.69	0.015	0.003	0.32	0.19	0.53

In this study, the exposure tests should reflect the corrosion environment for a real bridge scenario. At the Padma and Hardinge sites, the test samples were installed in the special design cabinet that resembles real environmental conditions without rain. At the Jamuna site, the samples were installed above and below of the lower flange of bridge.

The test sites’ distance from the coastline differed. The Padma 1, Padma 2, Hardinge 1, and Jamuna 2 sites were selected as exposure sites to investigate the effect of airborne salt amounts for one year. Temperature and relative humidity were measured for the same test sites during 2014-2020.

The airborne salt amount was measured via the dry gauze method (JIS Z 2382).The salinity gauges were collected every month from four (Padma 1, Padma 2, Jamuna 2, and Hardinge 2) out of the six test sites. Temperature and relative humidity were measured with an Ondotori thermo-recorder manufactured by T&D. Temperature and humidity data were collected at three-month intervals from four test sites during the study. The time of wetness was calculated from the measured data as the total hours during which the temperature is over 0°C and the relative humidity is over 80%(ISO9223, 1992).Samples of various grades of steel were collected after six months and after one, three, and five years. The average of thickness losses of the top and bottom of different specimens were calculated.

3 RESULTS AND DISCUSION

3.1 *Environmental Factors*

The Chloride (Cl^-) concentration of river water at the test sites was measured at the beginning of the exposure test. Table 3 shows the Cl^- concentration of river water at various test sites. The river water at the test sites was fresh (within 1 to100 ppm), and the amount of airborne salt seemed unaffected by Cl^- in rivers. Therefore, test specimens have very little or no chance of Cl^- contamination from the river water.

Table 3. Cl^- concentration of river water at atmospheric exposure test sites.

Site	Distance from sea (Km)	River water	
		Cl- concentration (ppm)	Collected date and Time
Jamuna	240	1.88	27 February 2014, 14:00 LST
Hardinge	265	12.1	26 February 2014, 16:30 LST
Padma 1	140	2.92	25 February 2014, 12:23 LST
Padma 2	130	2.42	25 February 2014, 15:30 LST

The amount of rust formation on the steel structures strongly depends on the environmental conditions of the test sites. Table 4 shows measurements of the environmental factors at various test sites from February to November in 2014. The average temperature and relative humidity at test sites were relatively high. Generally, the amount of airborne salt decreases as distance from the sea increases, but the amount of airborne salt at three sites (except Padma1) in Bangladesh was high despite the sites' distance from the sea.

Table 4. Values of the environmental factors measured from February 2014 to February 2015 at different test sites.

Site	Distance from the sea (km)	Amount of airborne salt (mdd)	Average temperature (°C)	Average relative humidity (%)	Time of wetness* (%)
Jamuna	240	0.082	27.6	80.0	60.0
Hardinge	265	0.071	28.1	78.5	57.8
Padma 1	140	0.020	29.0	79.4	59.3
Padma 2	130	0.069	29.2	79.9	58.0

*Time of wetness: when relative humidity is over 80%.

The monthly variations of average temperature, relative humidity, and time of wetness from February 2014 to February 2019/2020are shown in Figure 2-4.The maximum and minimum average temperatures, relative humidity, and time of wetness were found for each month and year, respectively. The average temperature was over 25°C from March to October. The relative humidity was over 80% from June to October. The time of wetness was above 60% from June to October. The time of wetness was high for all observation sites. Bangladesh has high humidity; strong monsoonal southwesterly winds bring a lot of moisture from the Bay of Bengal.

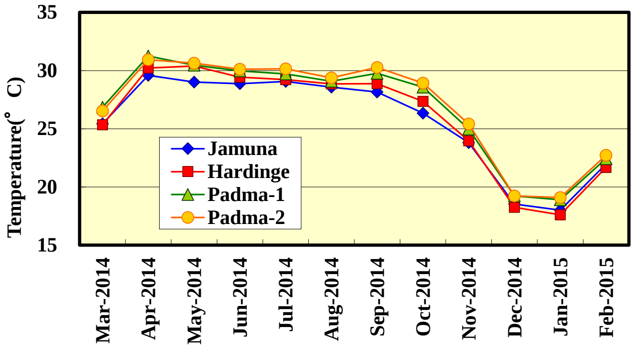

Figure 2. Monthly variation of the average temperature at each site from February 2014 – February 2019/2020.

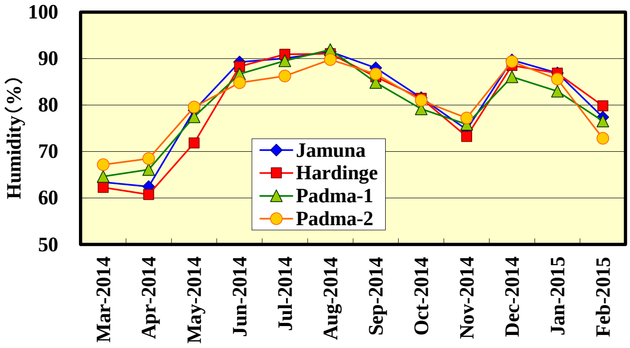

Figure 3. Monthly variation of relative humidity at each site from February 2014 – February 2019/2020.

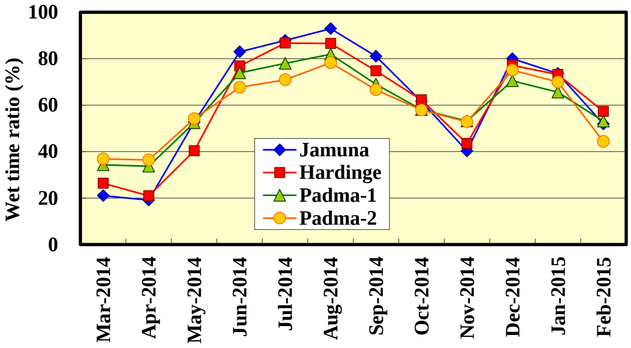

Figure 4. Monthly variation of time of wetness at each site during February 2014 – February 2019/2020.

The monthly variation of airborne salt at various test sites appears in Figure 5. The changes in the amount of airborne salt are almost the same at all exposure test sites. The maximum amount of airborne salt appears in May. During this month, a strong low-level southerly wind from the Bay of Bengal prevails in Bangladesh, increasing the amount of airborne salt (which then decreases due to heavy monsoonal rain).

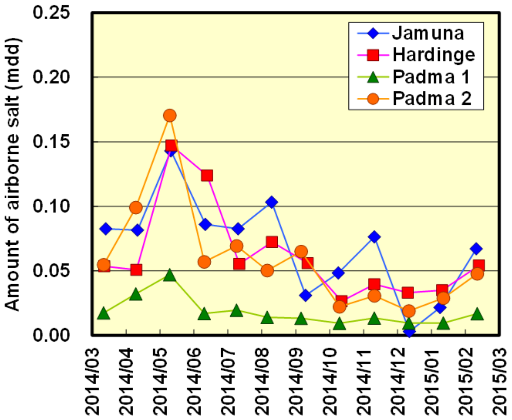

Figure 5. Monthly variation of the amount of airborne salt at each test site fromFebruary 2014 – February 2015.

The origins of airborne salt at various test sites appear in Figure 6. Large amounts of NO^{3-} and SO_4^{2-} were observed, along with Cl^-. In Bangladesh, airborne salt may come from sources in addition to the sea. Soil dust is another possible source of airborne salt(White and Broadley, 2001). The exposed gauge became gray due to a lot of soil dust. Bangladesh is an agricultural country, and farmers use much fertilizer [$(NH_4)_2SO_4$, NH_4NO_3] on their land for crops. These anions seemed to come from soil.

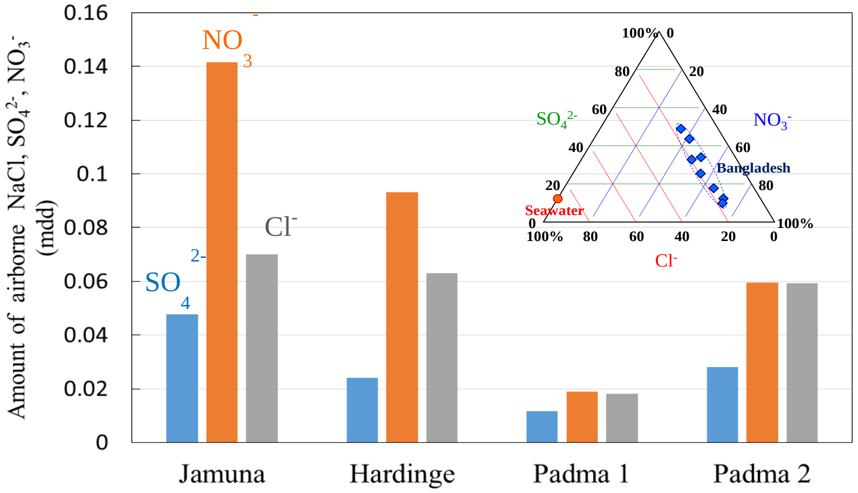

Figure 6. Origin of airborne salt at various test sites in Bangladesh.

3.2 *Thickness Loss of Weathering Steel and of Conventional Steel*

The appearance of weathering steel at various test sites is shown in Figure 7. Some sediment appeared on the specimen's surface on the top side. The color of rust became darker with time.

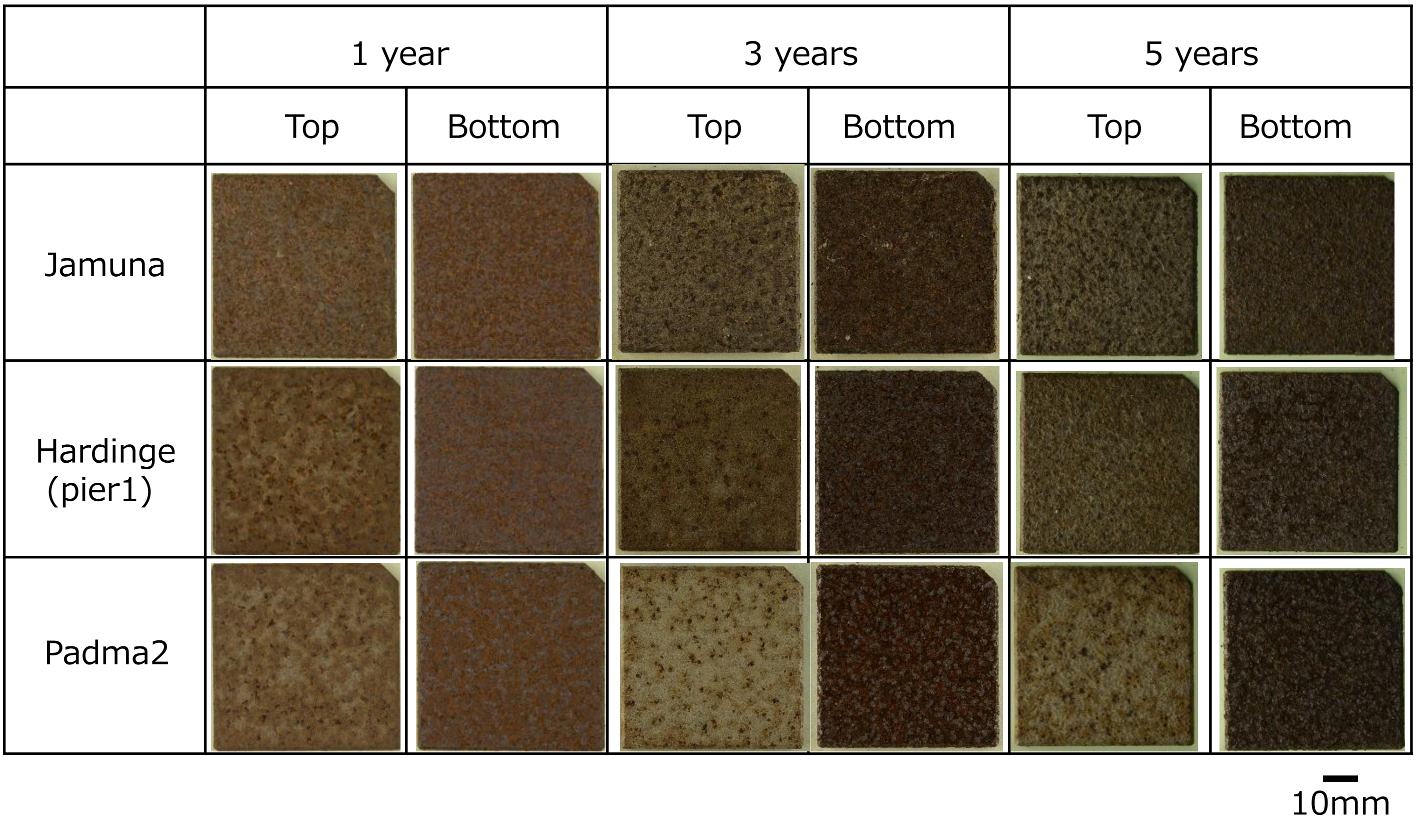

Figure 7. Appearance of weathering steel at various test sites.

The corrosion loss of weather steel at various test sites appears in Figure 8. The corrosion losses were less than 0.03 mm at all exposure test sites. For weathering steel in Japan, 0.03 mm of corrosion loss in 1 year is the applicability criterion for weathering steel (Public Works Research Institute 1993). The maximum corrosion loss appeared at the top side of Jamuna, Hardinge, and Padma test sites.

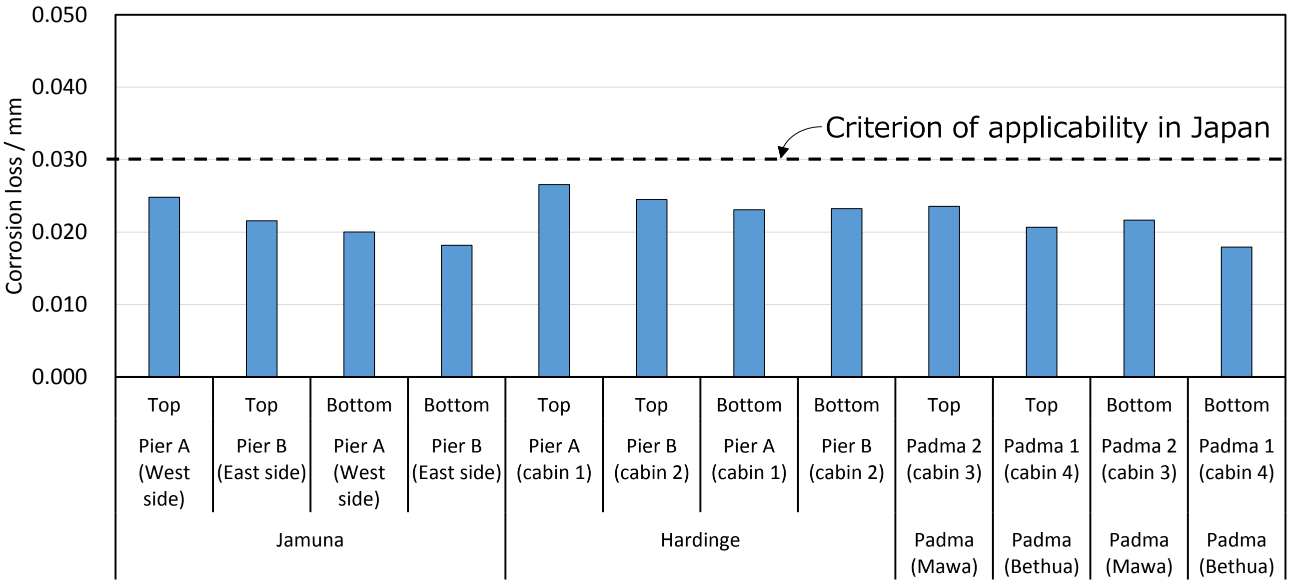

Figure 8. Comparison of the corrosion loss of weathering steel overtime at different test sites.

The corrosion loss of weathering steel (SMA) and of conventional steel (MA) at 1 year and at 3 years at each test site is shown in Figure 9.Weathering steel’s corrosion loss became gradually smaller overtime.

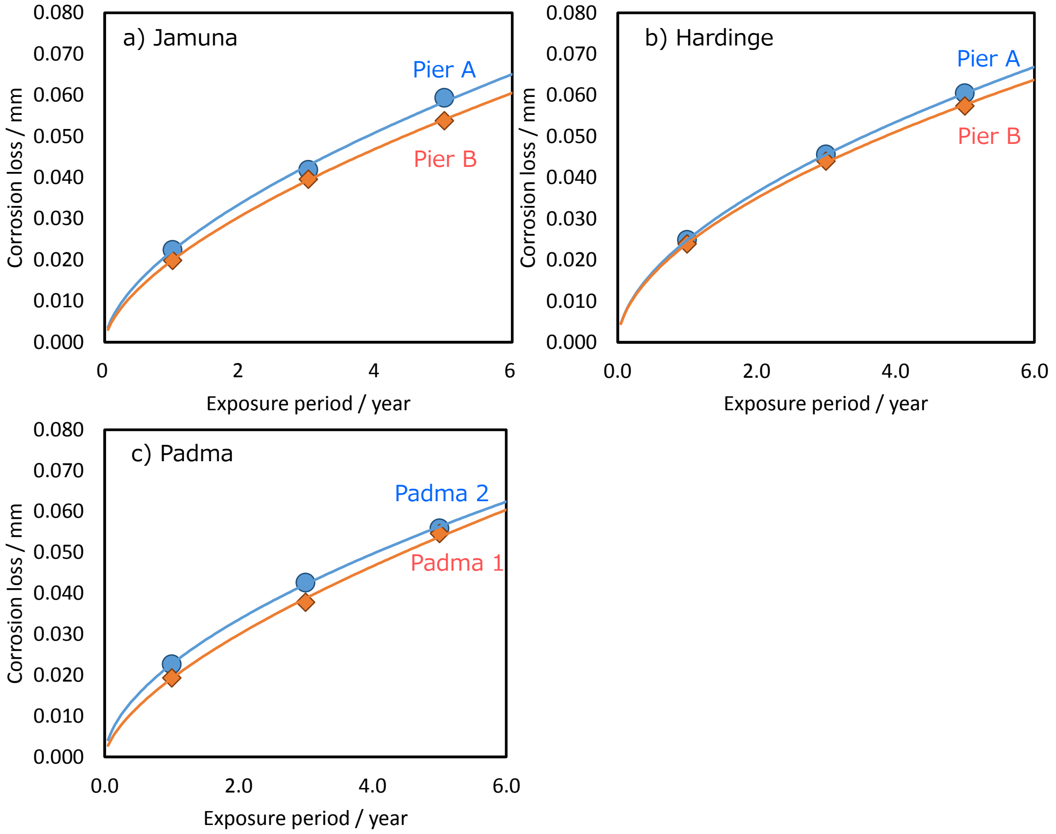

Figure 9. Corrosion loss of weathering steel (SMA) and of conventional steel (SM) at each test site during the study. a) Jamuna, b) Hardinge, c) Padma.

Figure 10 shows time-dependent corrosion loss and the estimated corrosion loss after100 years for weathering steel. The estimated corrosion loss of the weathering steel was less than 0.5 mm in 100 years at each site. These results confirmed the possible use of weathering steel in Bangladesh.

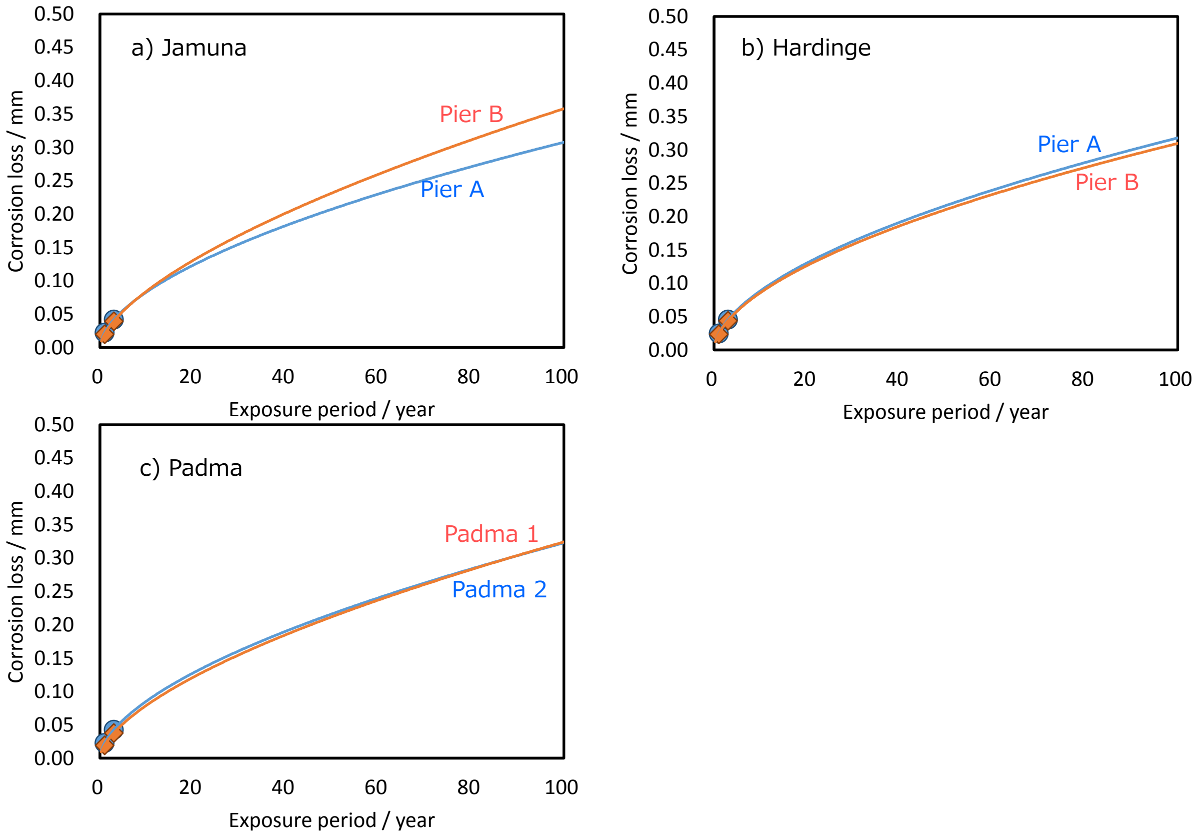

Figure 10. Time dependence of corrosion loss and estimated corrosion loss over100 years for weathering steel. The corrosion loss is the average value between the top and the bottom side. Regression equation: $Y=A.X^B$ a) Jamuna, b) Hardinge, c) Padma.

4 CONCLUSIONS

- The average temperature was over 27°C,and relative humidity was around 80% at each test site. They are relatively high compared with those of Japan. The amount of airborne salt in the test sites of Bangladesh does not depend on distance from the coastline, however
- Corrosion losses of weathering steel after 1 year were less than 0.03mm at each exposure test site. We calculated corrosion losses at 1,3, and 5 years. The results were all under 0.5 mm after 100 years at each exposure test site. Therefore, according to Japanese corrosion loss criteria, weathering steel can be used in Bangladesh.

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